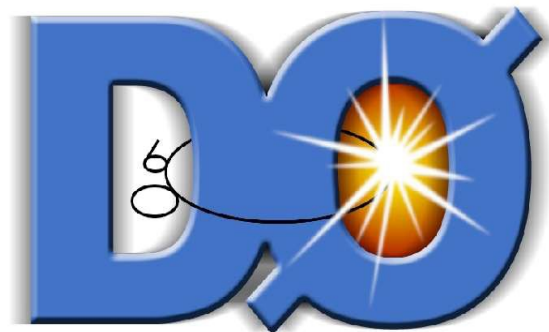
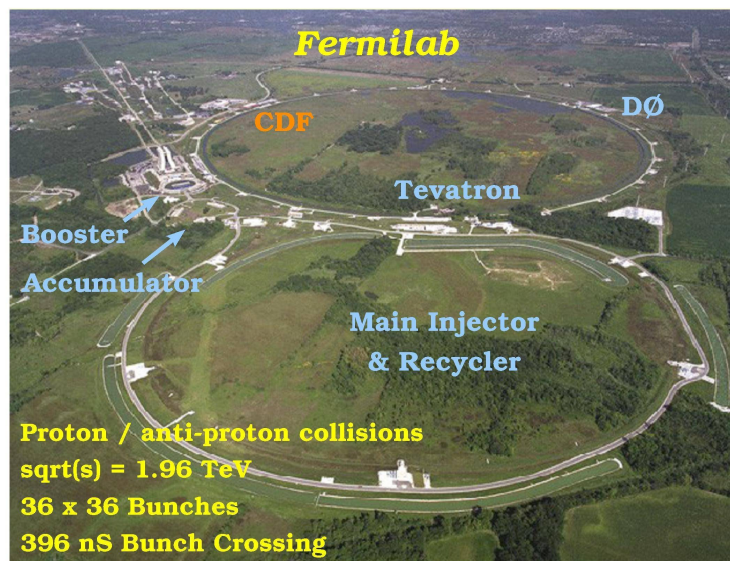


# Selected Topics from $t\bar{t}$ /single top Production at the Tevatron

Weiming Yao (LBNL)

On behalf of the CDF and D0 Collaborations

LHCP 2015, August 31-September 5, 2015 St. Petersburg, Russian



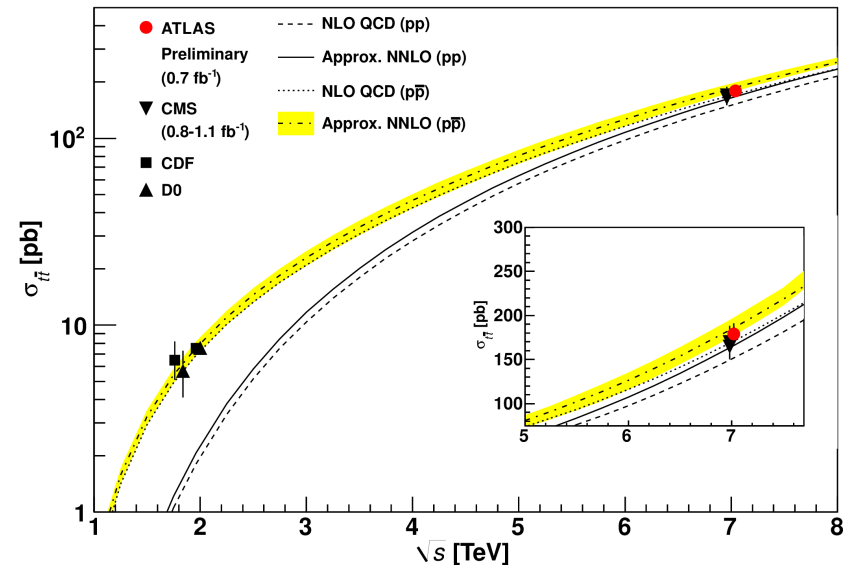
# Outline

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- Introduction
- Recent ttbar inclusive and differential cross sections
- Recent single top production cross sections
- All the measurements are based on full dataset( $10\text{fb}^{-1}$ )
- Conclusion
- More Details:
  - <http://www-cdf.fnal.gov/Physics/S15CDFResults.html>
  - <http://www-d0.fnal.gov/Run2Physics/WWW/results/top.htm>

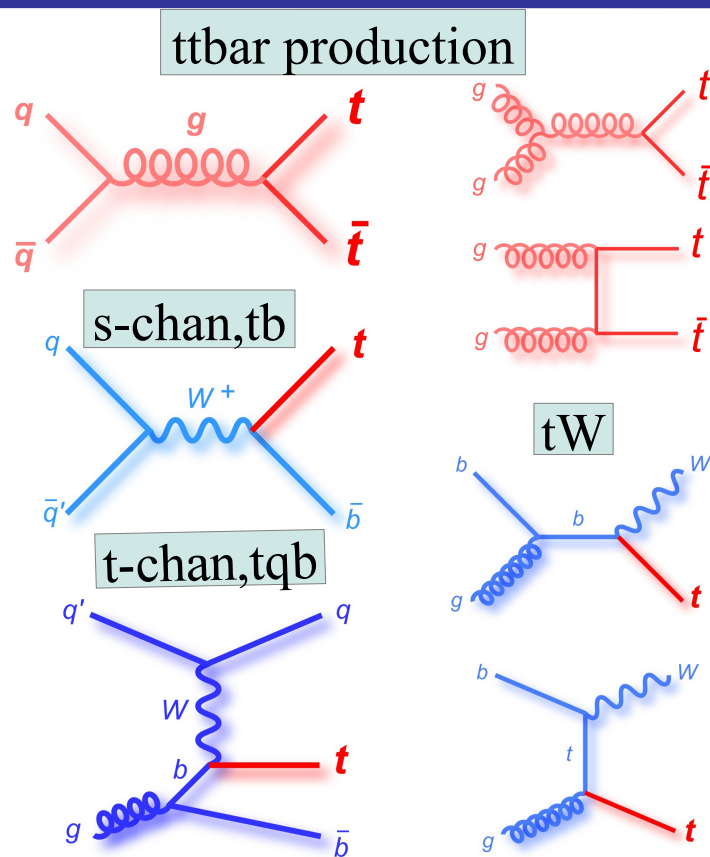
# Introduction

- Top-quark was discovered at the Tevatron by CDF & D0 in 1995, the heaviest quark discovered so far.
  - $M_t = 176 \pm 12.8$  GeV (1995)
  - $M_t = 174.34 \pm 0.76$  GeV (2015)
- First bare quark ever observed due to a short lifetime of  $5 \times 10^{-25}$  s  $\ll \tau_{\text{QCD}}$
- Large Yukawa coupling ( $y_t \sim 1$ ) to Higgs boson may play special role in ESB.
- Studies of top-quark production provide a stringent test of QCD and are sensitive to physics beyond the standard model (BSM).



# Top-quark Production at Tevatron

- Top-quark is predominately produced in  $q\bar{q}$  annihilation (85%) while at LHC the gluon fusion dominates more than 85%.
- Top-quark can also be produced singly in electroweak processes, which was first discovered by CDF & D0 in 2009 via s-, t-channels while the  $wt$  contribution is small.
- Top production at Tevatron is complementary to LHC and provides unique test of QCD.

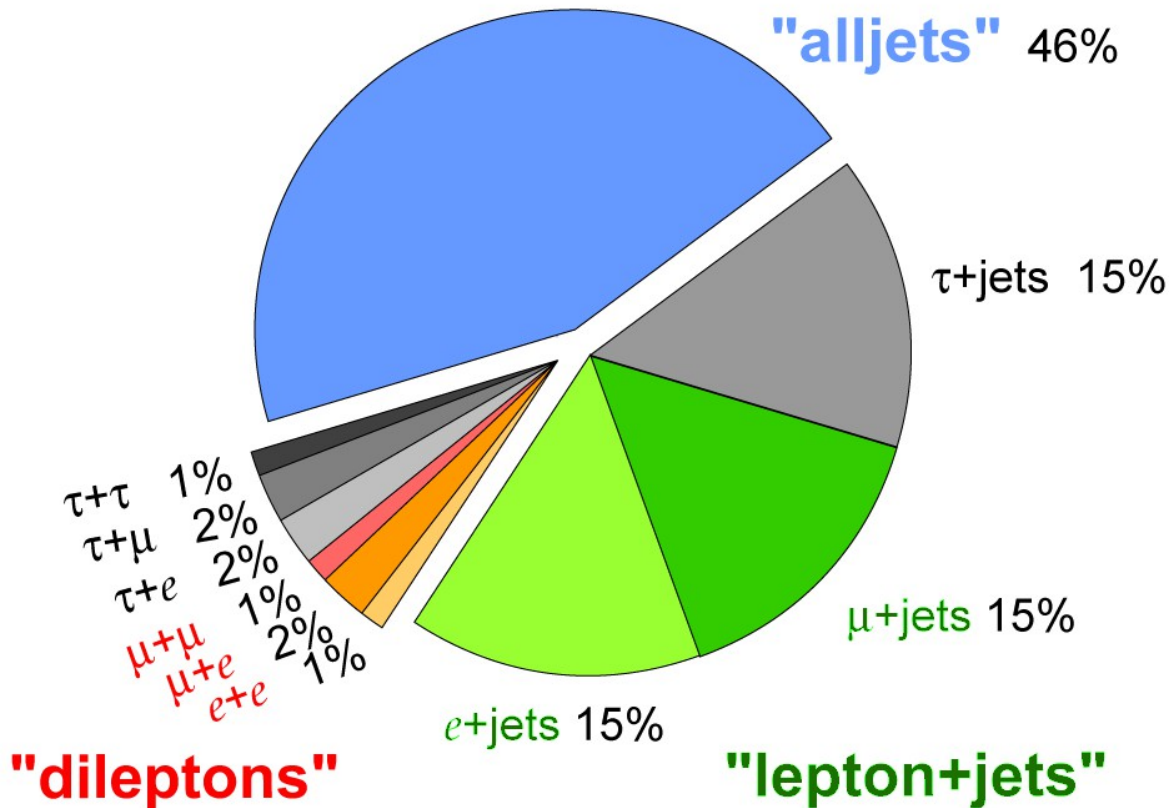


NNLO ( $m_t=172.5$ , PRL 109, 132001)	$tt\bar{t}$ [pb]	$t\bar{t}$ [pb]	$tqb$ [pb]	$tW$ [pb]
Tevatron(1.96TeV)	7.24	1.04	2.26	0.30
LHC(8 TeV)	248.50	5.50	89.14	19.50
Ratio (LHC/Tevatron)	34	5	39	65

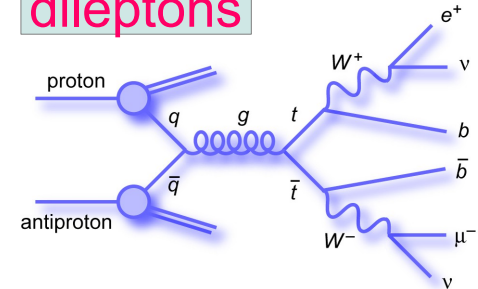
# Top-quark Decay in SM

- Top-quark predominately decays into  $Wb$  with  $B(t \rightarrow wb) = 100\%$ , final states determined by  $W$  decays.

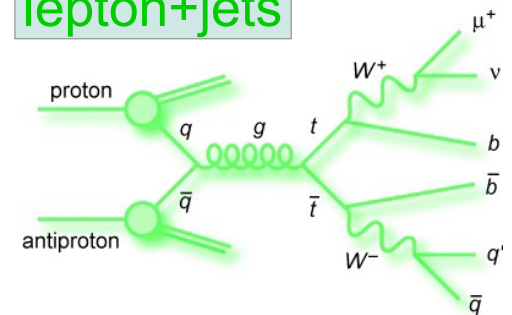
## Top Pair Branching Fractions



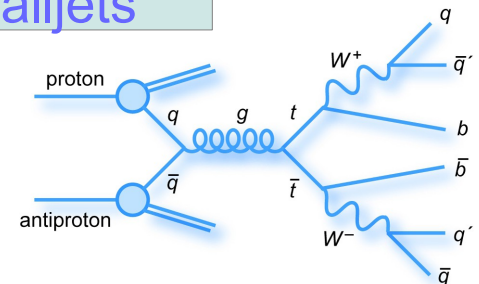
### dileptons



### lepton+jets

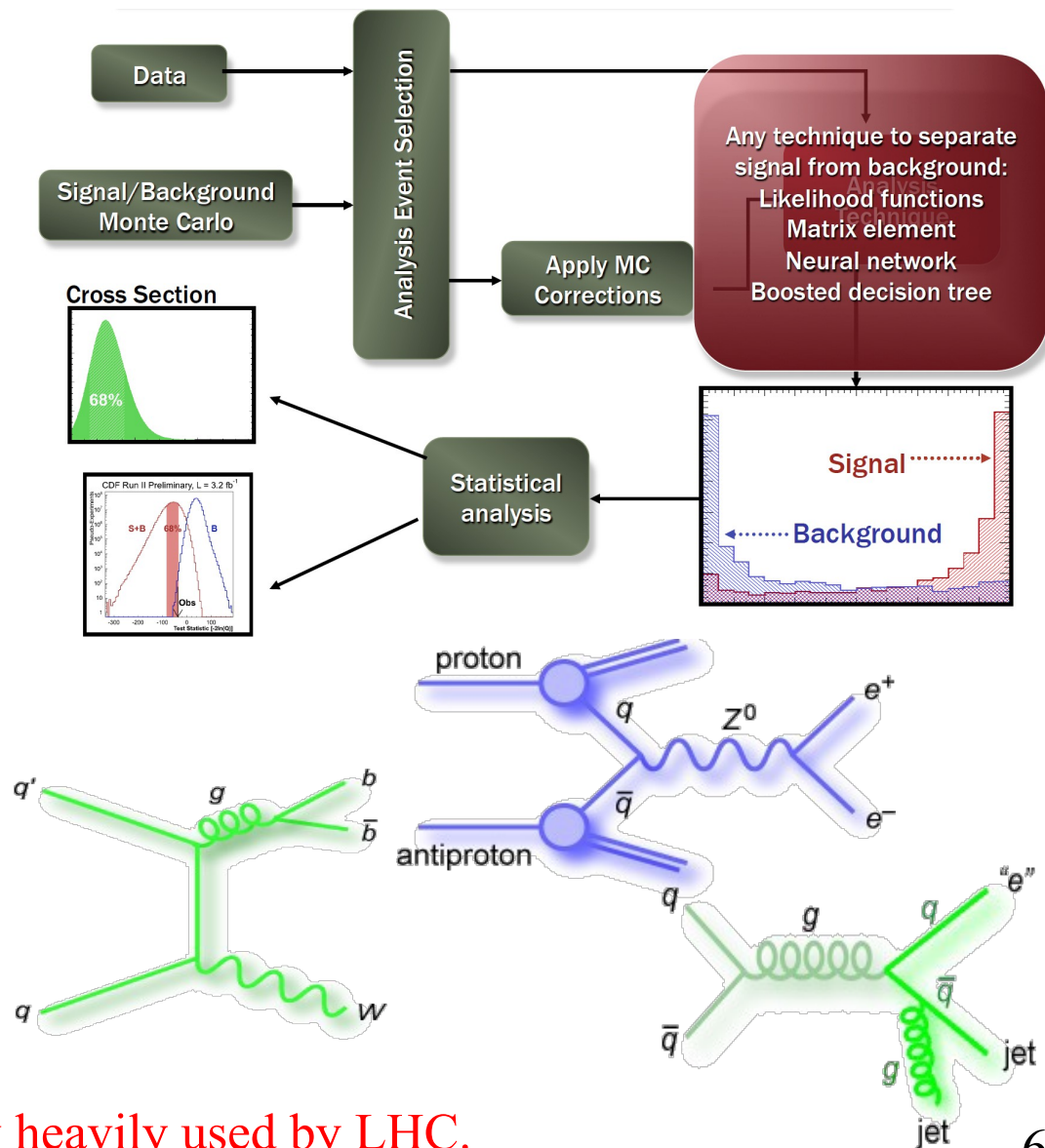


### alljets



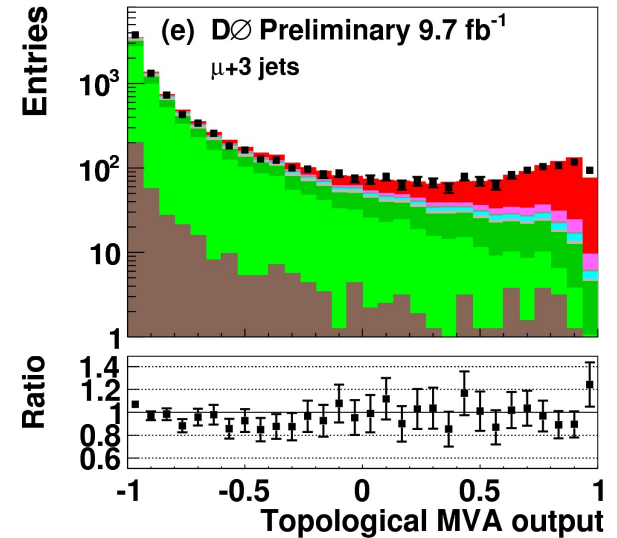
# Events Selection and Analysis Strategies

- Select isolated lepton(s), high missing  $E_t$  from neutrinos, one or more btagged jets:
- **The  $t\bar{t}$  final states:**
  - Dilepton: 2 isolated leptons
  - Lepton+jets: one isolated lepton+jets
  - Alljets: 0 isolated leptons.
- **Single top production:**
  - S-chan: one isolated lep+ 2bs
  - T-chan: one isolated lep+1b+q
- **Backgrounds:**
  - W+jets is dominated in l+jets.
  - Z+jets is dominated in dileptons.
  - Multijet is dominated in allhad.
- NLO MC calibrated using data control samples.
- Using MVA to separate S from B
- MVA pioneered by Tevatron and now heavily used by LHC.



# ttbar Inclusive Cross Section using Full dataset

- D0 recently updated ttbar xsec using improved analysis in l+jets and dilepton with full dataset:
  - l+jets: divided six subsamples based on lepton type & njets, and each trained its own BDT with 20 variables plus b-tag MVA.
  - Dilepton: divided four subsamples and use b-tag MVA of leading jet as discriminant



- Performed simultaneous fits across all samples(pb):

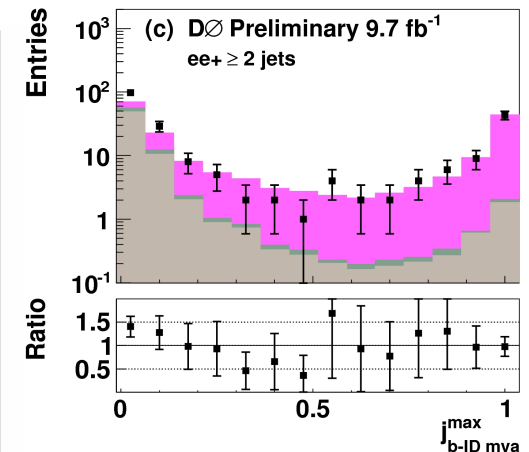
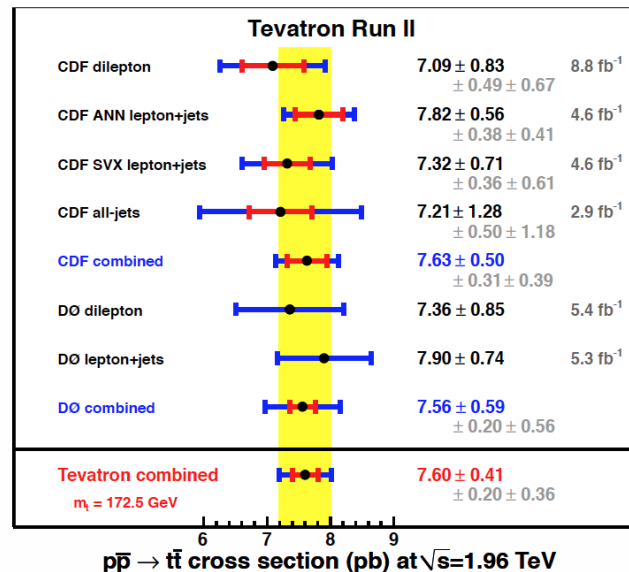
→ Ljets:  $\sigma_{tt} = 7.63 \pm 0.14 \pm 0.59$

→ Dilep:  $\sigma_{tt} = 7.60 \pm 0.34 \pm 0.60$

→ Comb:  $\sigma_{tt} = 7.73 \pm 0.13 \pm 0.55$

→ NNLO:  $\sigma_{tt} = 7.35^{+0.23}_{-0.27}$  (mt=172.5)

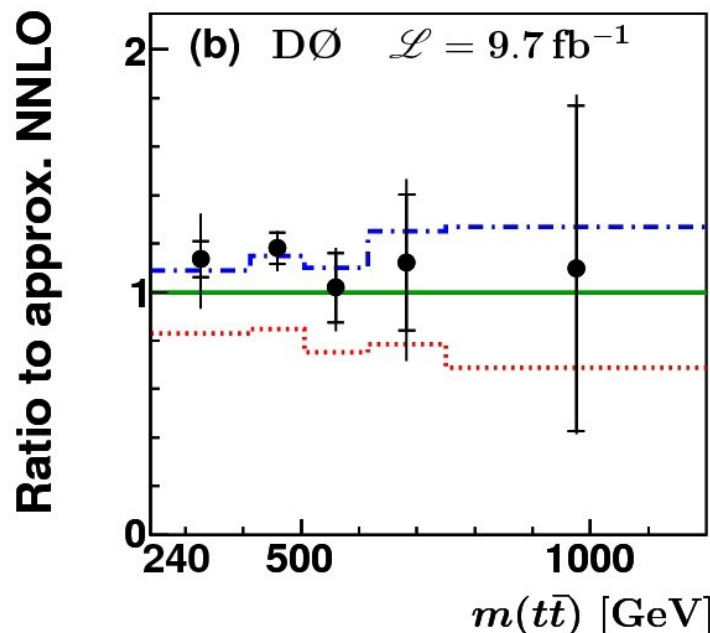
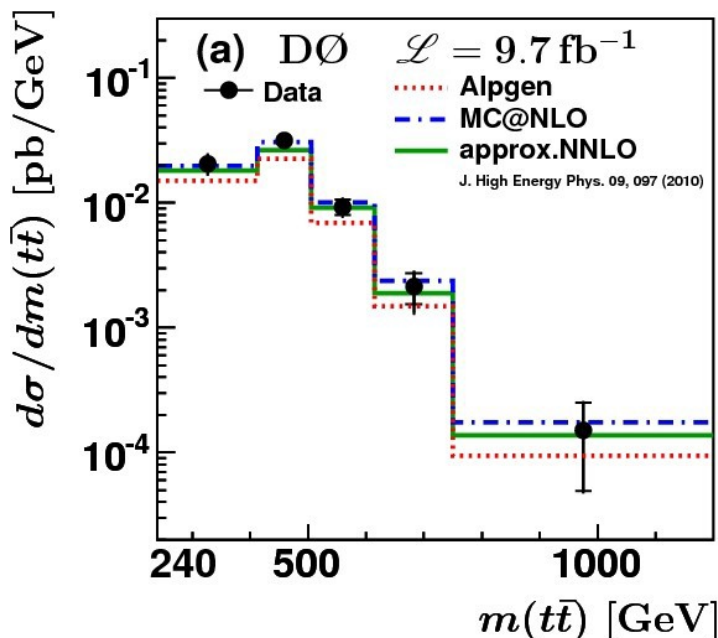
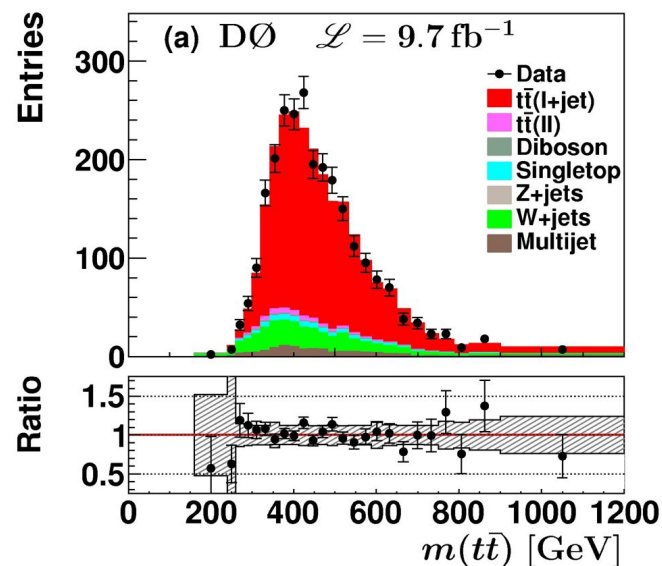
→ Consistent with previous Tevatron averages in PRD 89, 072001, 2014.



D0 Note 6453-CONF

# Differential Cross Section

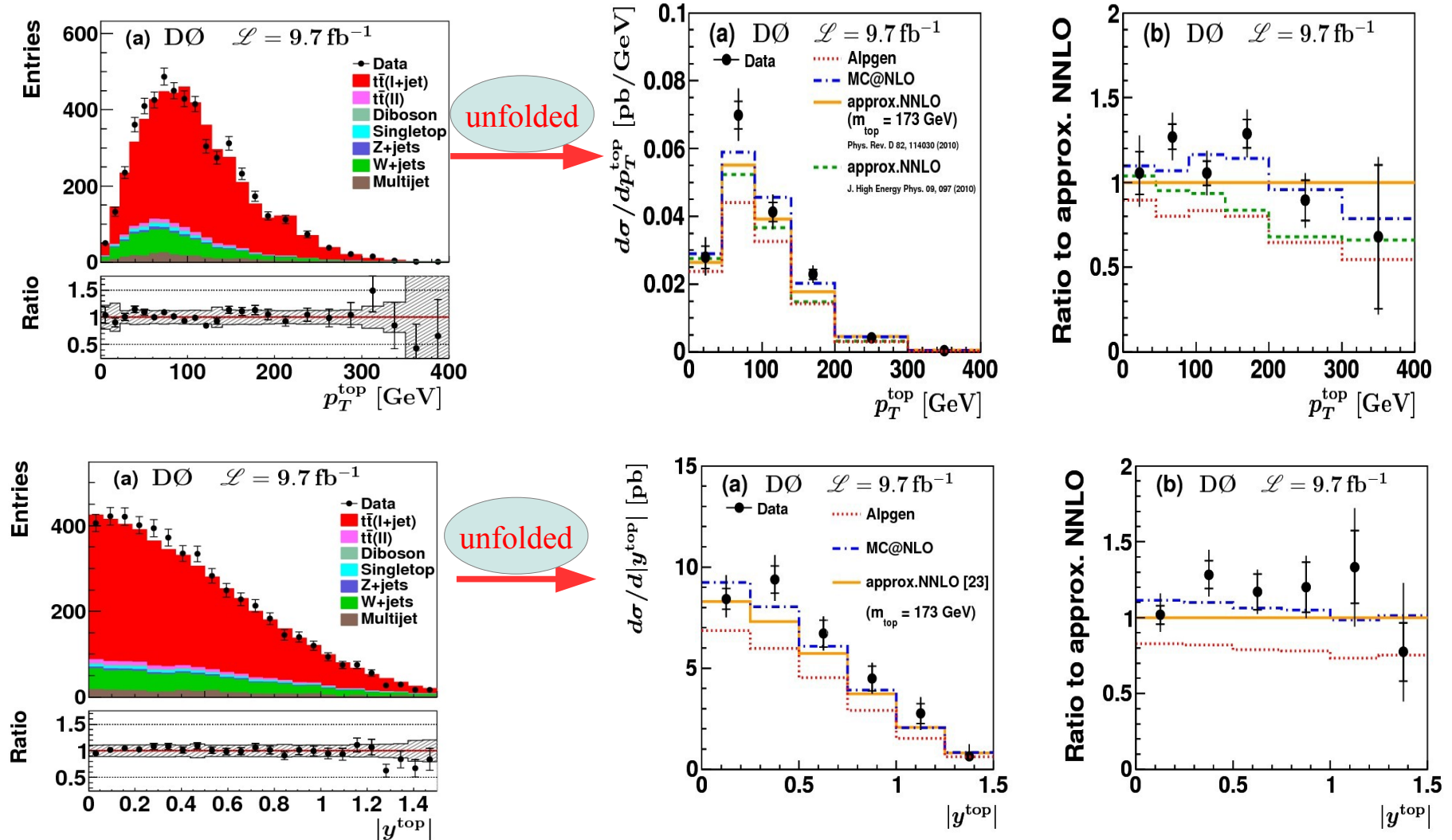
- Measuring differential cross section as function of  $m_{t\bar{t}}$ ,  $p_{t\bar{t}}$ ,  $y_t$  is interesting, sensitive to top production mechanisms and can be measured using fully reconstructed  $t\bar{t}$  in the b-tagged lepton + 4 jets.
- After unfolded up to parton-level, data are consistent with MC@NLO predictions.



Unfolded

# More Differential Cross Sections

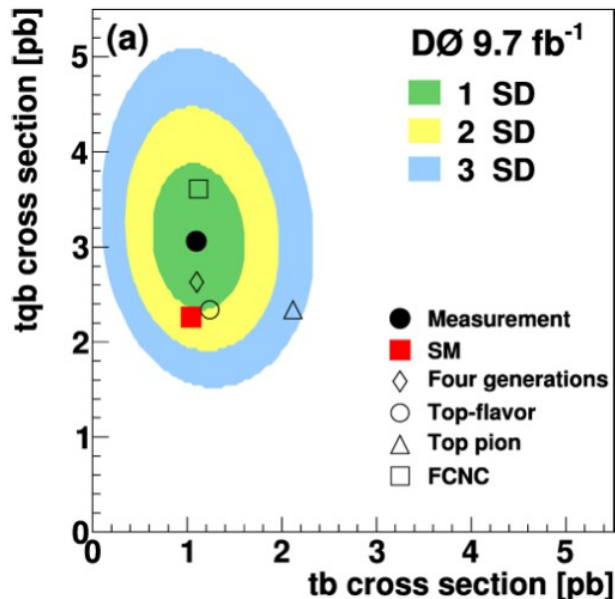
- Data and unfolded distributions for  $p_{T,t}$ ,  $y_t$  after correcting detector effects:



- Unfolded data are in reasonable agreement with MC@NLO.

# D0 Single Top Analysis

- Measuring each single top cross section simultaneously in lepton+2 or 3jets with 9.7fb<sup>-1</sup>.
- Trained 3 MVAs that select different evnt kinematics to separate tqb and tb signals from backgrounds.
- Obtained tqb and tb cross sections by combining of 3 MVAs using a BayesianNN statistical tool:



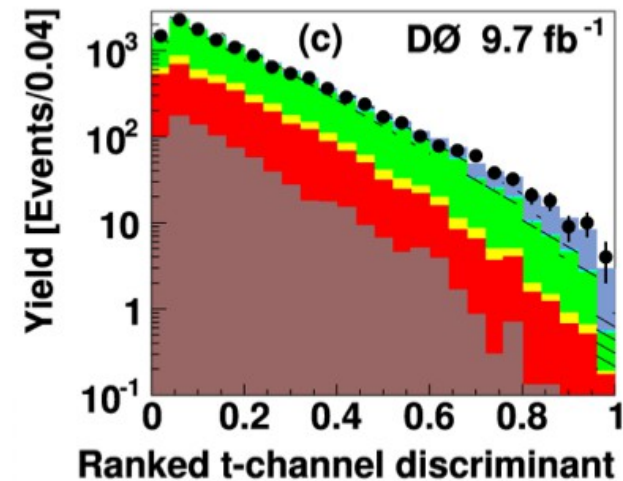
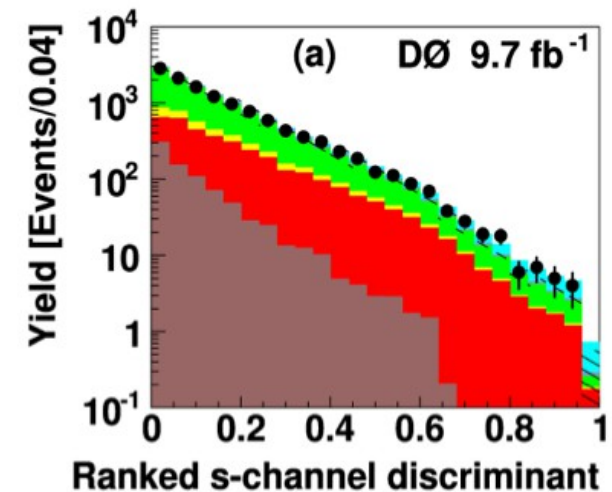
$$\sigma_{s+t} = 4.11^{+0.60}_{-0.55} \text{ pb}$$

$$|V_{tb}| > 0.92 \text{ at } 95\% \text{CL}$$

$$\sigma_s = 1.10^{+0.33}_{-0.31} \text{ pb}$$

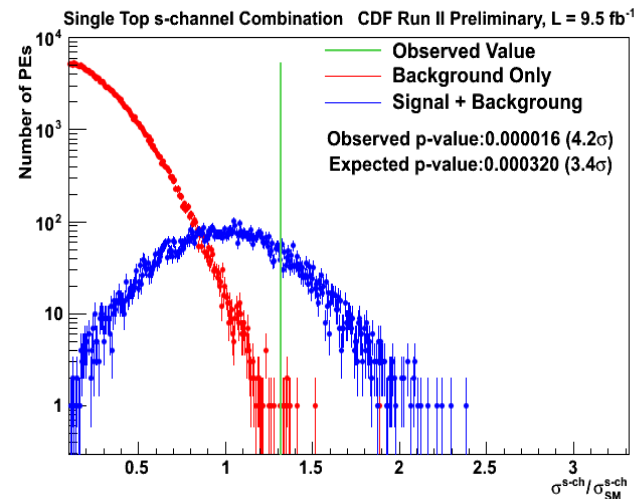
$$\sigma_t = 3.07^{+0.54}_{-0.49} \text{ pb}$$

Consistent of first s-chan evidence at 3.7σ !

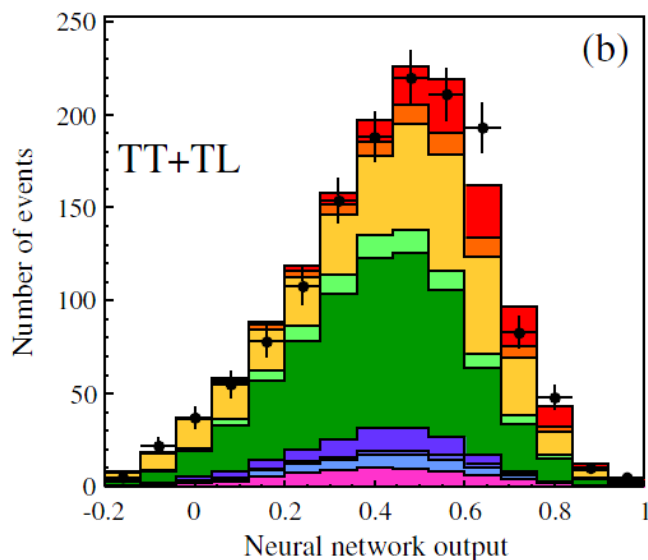


# CDF s-channel Single Top Analyses

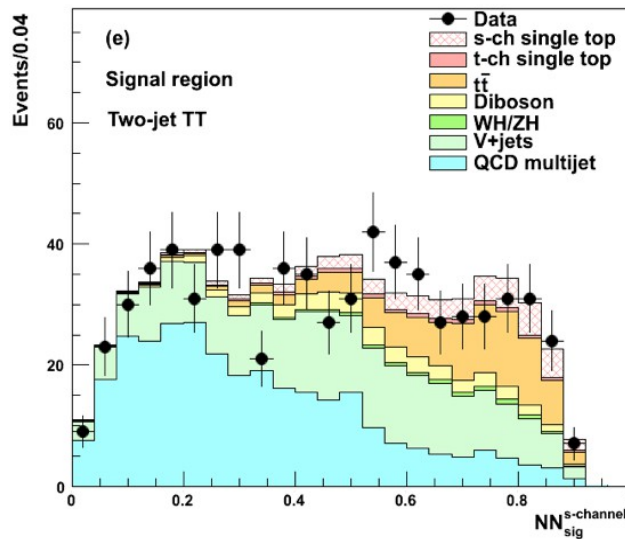
- CDF updated s-channel tt search using full dataset based on  $WH \rightarrow l\nu b\bar{b}$  search strategies & selections
  - L+jets: Lepton + 2 or 3 jets with 1 or 2 btags
  - Met+jets: orthogonal to L+jets selection
- Measured s-chan xsec combining both analyses.



L+Jets



Met+Jets



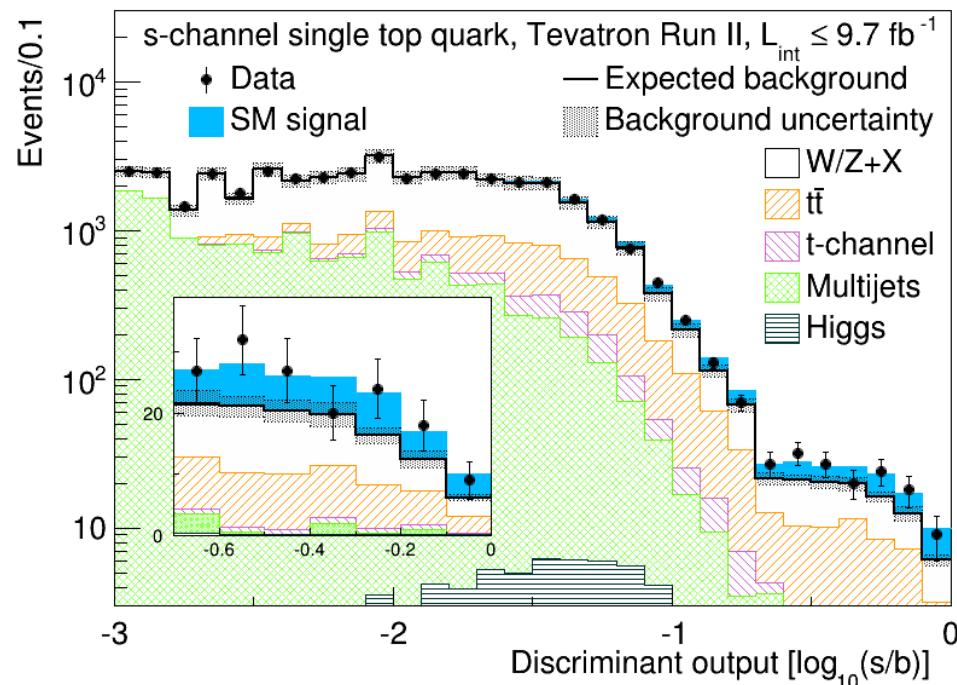
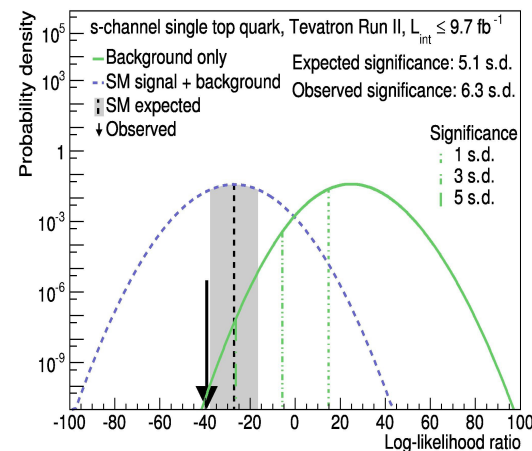
CDF combination:  
 $\sigma_s = 1.36^{+0.37}_{-0.32} \text{ pb}$

Corresponds to a s-channel evidence at  $4.2\sigma$

PRL 112,231805 (2014)

# Observation of s-chan Single Top Production at Tevatron

- Summed  $\log(s/b)$  from each s-chan discriminant bin in  $CDF(l+jets, met+jets)$  &  $D0(l+jets)$  to form a discriminant.
- Fitted using Bayesian statistical analysis with all systematic & correlations.
- **First s-chan single top is observed at Tevatron with  $6.3\sigma$**



s-channel single top quark, Tevatron Run II,  $L_{int} \leq 9.7 \text{ fb}^{-1}$

Measurement

CDF  $l+jets$

CDF  $\cancel{e}_T+jets$

CDF combined

D0  $l+jets$

Tevatron combined

Theory (NLO+NNLL)

$1.05 \pm 0.06 \text{ pb}$  [PRD 81, 054028, 2010]

Cross section [pb]

$1.41^{+0.44}_{-0.42}$

$1.12^{+0.61}_{-0.57}$

$1.36^{+0.37}_{-0.32}$

$1.10^{+0.33}_{-0.31}$

$1.29^{+0.26}_{-0.24}$

$m_{top} = 172.5 \text{ GeV}$

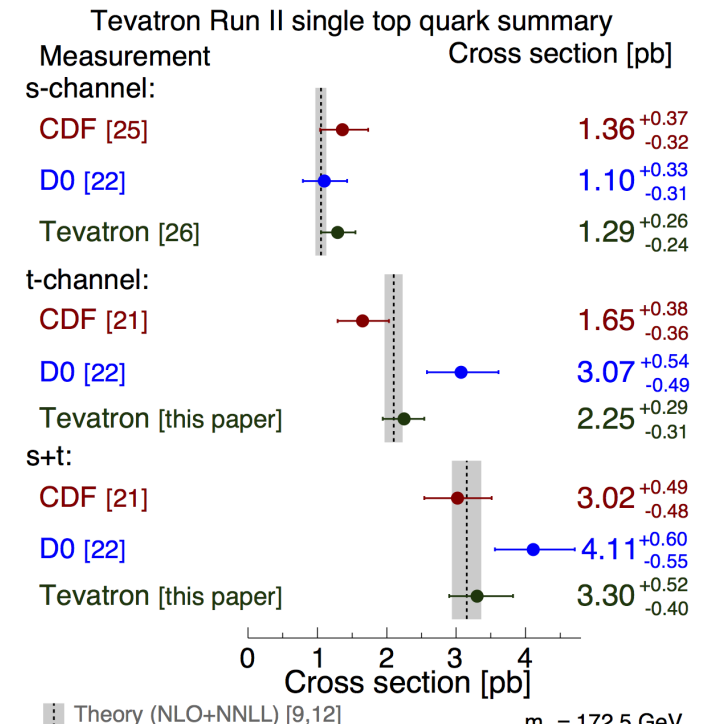
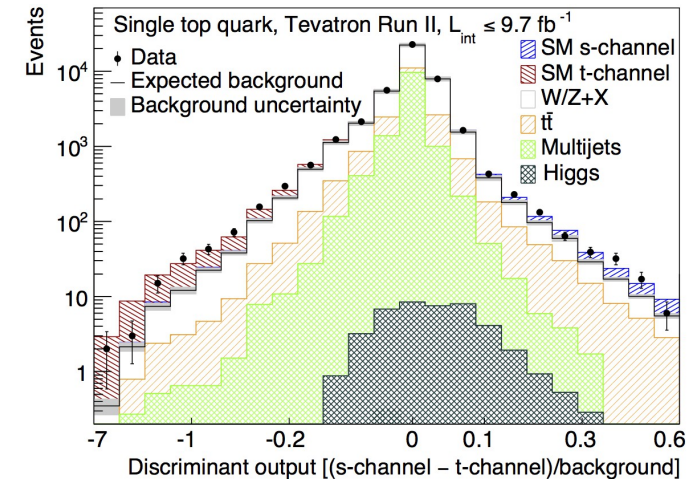
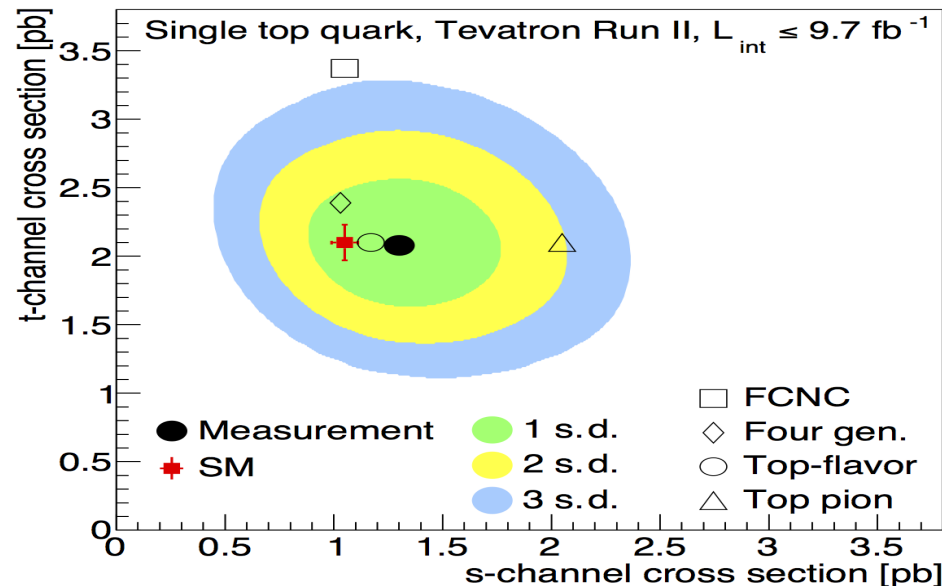
0 1 2

Cross section [pb]

# Tevatron Final Single Top Measurements

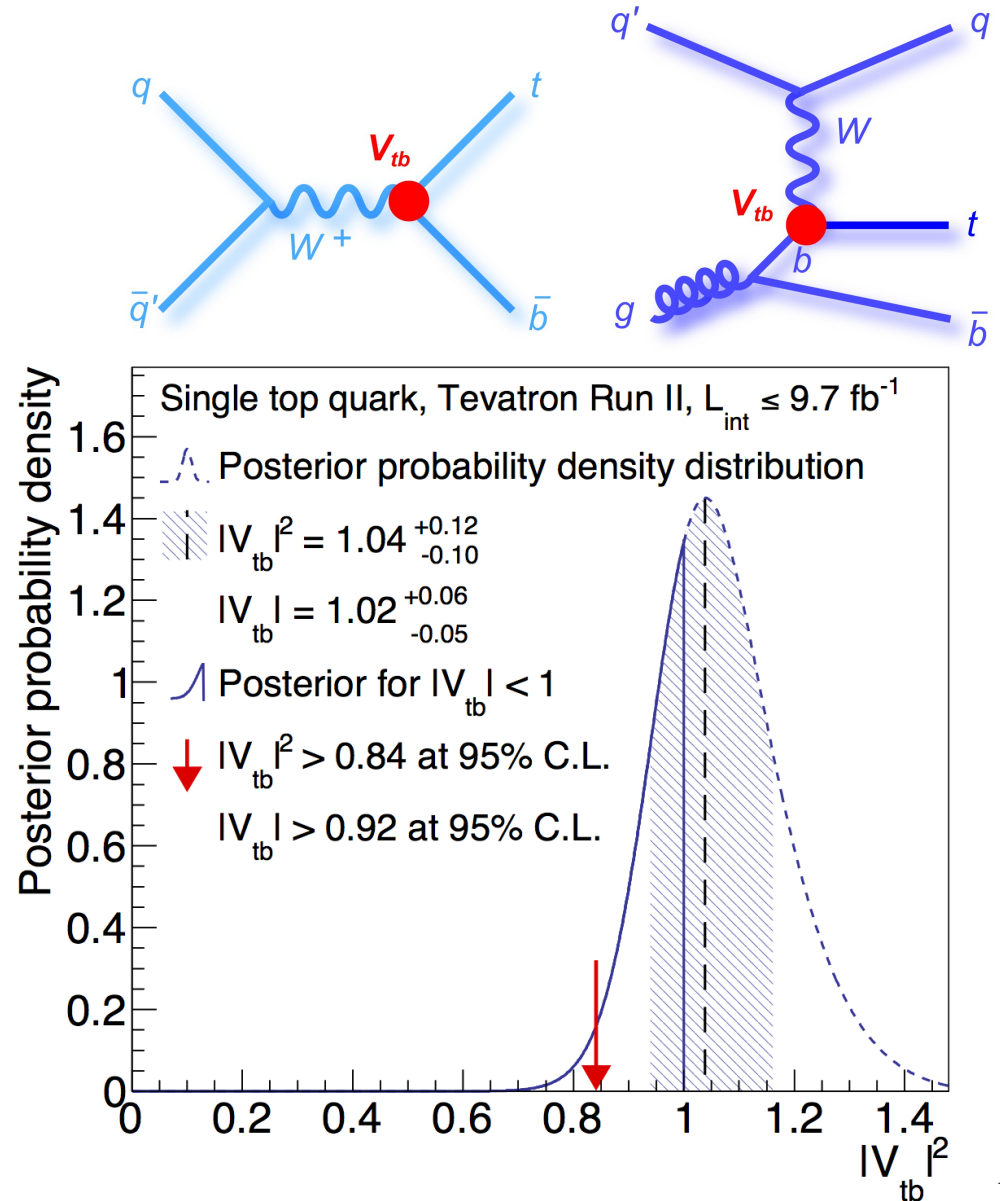
- Combined t-, s-chan contributions from each discriminant bin to form a discriminant as  

$$(s\text{-chan} - t\text{-chan})/\text{background}$$
- Fitted s-, t-, and s+t cross sections including all systematic and correlations are in good agreement with SM predictions.



# Measurement of $|V_{tb}|$

- Assuming SM top decay, the single top cross section is proportional to CKM matrix element  $|V_{tb}|^2$ . Consequently,  $|V_{tb}|$  can be measured directly without any assumptions on SM  $\sigma_s/\sigma_t$  ratios, generations, or unitarity.
- Form a Bayesian posterior probability density for  $|V_{tb}|^2$  by assuming a flat prior.
- Tevatron obtained:**
  - $|V_{tb}| = 1.02^{+0.06}_{-0.05}$
  - $|V_{tb}| \geq 0.92$  at 95% C.L.



# Conclusion

- Selected  $t\bar{t}$  and single top results at Tevatron are presented with full  $10^{-1}$  fb.
- Study of top quark at Tevatron is complementary to LHC and provides an unique test of QCD predictions.
- CDF & D0 experiments are finishing their legacy measurements and the results are in excellent agreement with SM predictions.

